J Sci Educ Technol (2007) 16:395–400
DOI 10.1007/s10956-007-9064-4

Effects of a Demonstration Laboratory on Student Learning

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Published online: 26 June 2007

Abstract Laboratory and demonstration have long been used to supplement lecture in chemistry education. Current research indicates that students are better served by laboratories which exercise the higher-order cognitive skills, such as inquiry-based laboratories. However, the time and the resources available to perform these recommended types of laboratories are continually shrinking. Due to these factors, a demonstration-laboratory was designed to allow students to make observations through demonstration rather then through hands-on laboratory. For this study, the hands-on procedures of an inquiry style laboratory were replaced by an instructor demonstration of these same procedures. A significant difference was found between student conceptual understanding before and after the experiment, indicating that students performing the laboratory experiment and students viewing the demonstration-laboratory had an increase in conceptual understanding. However, no significant difference was found between the conceptual understanding of the two groups after the experiment, indicating that students learn roughly the same from both methods and that the demonstration-laboratory at least does no harm to the students conceptually. Long-term effects on student understanding were not measured. Student opinions comparing the demonstration laboratory to a hands-on laboratory were also collected and analyzed.

Keywords Demonstration · Guided inquiry · Laboratory · Mole relationships

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Background

Initially, the role and effect of demonstrations in both high school and college instruction was debated (e.g., Harty and Al-Faled 1983; Knox 1936; Eniaiyeju 1983; Cooke 1938; Carptenter 1936; Anibel 1926). Demonstrations were thought to be affective aids in increasing student's conceptual understanding in a summary of early opinion literature (Payne 1932). A meta-analysis of educational studies that examined the efficacy of demonstration revealed that demonstrations and/or laboratories are marginally more effective than lecture alone with little to no difference between demonstrations and laboratories (Knox 1936).

The effectiveness of demonstrations was revisited in a more recent study in the Saudi Arabian school system (Harty and Al-Faled 1983). Two classes were used to compare the lecture/demonstration to the lecture/laboratory styles of instruction. An attitude survey and an achievement test were administered before the study, immediately after the study, and again at a later time. Throughout the duration of the study, attitudes of both sets of students changed, but there was no significant difference between the two classes. However, when achievement scores were analyzed, both classes showed an increase in conceptual understanding; however, the lecture/laboratory group significantly outperformed the lecture/demonstration group. This seems to indicate that demonstrations are no substitute for a laboratory experience, although, demonstrations are beneficial when a laboratory experience is not an option, such as when sufficient funds are not available (Knox 1936).

A novel expansion of the use of demonstrations was an attempt to combine a demonstration with the use of an assessment, creating what was termed a demonstration assessment. The demonstration assessment is a two-step process. First, a demonstration is shown to the students

without explanations. Second, an assessment is administered covering the demonstration, asking students to draw conclusions and/or to propose explanations based upon observations made during the demonstration.

The effectiveness of the demonstration assessment was studied using two classes of freshman enrolled in a chemistry class for engineering majors (Deese et al. 2000). Both classes were given an end-of-course conceptual assessment and a pre- and post-attitude survey. There was no significant difference in attitude between the individual pre- and post-survey for either group or when the groups were compared. However, the treatment group did show a significantly greater conceptual understanding at the end of the course then did the control group. This seems to indicate that the demonstration assessment can be successful at improving student retention.

Demonstration assessments have proven very successful in increasing student understanding and retention of chemical principles (Bowen and Phelps 1997). Demonstrations themselves, in some studies, caused similar increases in student understanding. If this is the state of research into the use of demonstrations, what does the research have to say about the laboratory?

Domin (1999b) has identified four types of laboratory experiences which are used, to varying degrees, in chemical laboratory instruction: expository or verification, open inquiry, guided inquiry or discovery, and problem based instruction.

- Expository instruction is that in which students are asked to follow a detailed procedure in the hopes of verifying some already known fact. This is how most traditional laboratory experiments have been written.
- In an open inquiry style experiment, students design procedures to investigate some stated system. Through careful observations and analysis of data collected, students are expected to construct an understanding of the concept at hand.
- A discovery or guided inquiry experiment is similar, except that students are given a procedure to follow and some idea of what data to collect, leaving them only to analyze their data to construct the conceptual understanding.
- In a problem based setting, students apply chemical knowledge to design experiments in order to solve a posed problem. The students then carry out their procedures, modifying them as necessary, in order to arrive at a solution.

The last three styles of instruction require that the students must exercise higher order cognitive skills in order to accomplish the laboratory activity. The expository style is often highly criticized for its failure to foster these critical thinking skills.

It would be expected, therefore, that laboratory manuals would tend to focus on these latter three styles of instruction. However, if an examination is made of current laboratory manuals (Domin 1999a) and current laboratory instruction practices (Hilosky et al. 1998), what can be concluded? By and large, the laboratory manuals compared indicate very little requirement for higher order-thinking skills. Often only the titles of the lab manuals include inquiry, but the laboratory instruction and experience does not follow inquiry methods. It has been well established that laboratories that are inquiry-oriented and are activities-based can significantly increase student understanding (Abraham et al. 1997; Shilad 1999; Staver and Small 1990). The use of inquiry style experiments has also been shown to increase conceptual understanding for students of all ability levels (Pavelich and Abraham 1979).

Renner and Marek (1990) compared inquiry style instruction with traditional instruction, which they termed IVP, or Inform-Verify-Practice, instruction. In contrast the inquiry style, sometimes termed the learning cycle method, consists of students exploring an unknown concept, inventing or constructing the concept for themselves, and then expanding on the concept (Lawson 1988; Abraham and Renner 1986).

Due to the emphasis placed on making observations during the course of an inquiry style experiment, an inquiry style laboratory was chosen as the focus for this study. An attempt was made in this study to extend the idea of a demonstration assessment to the laboratory by replacing student performance of an experiment with a demonstration of the same experiment by the instructor, while leaving aspects of data collection, analysis, and laboratory report unchanged. The research questions that guided this investigation were:

1. How does student understanding of the mole relationship of chemical reactions change after the student experiences a laboratory experiment?
2. How does student understanding of the mole relationship of chemical reactions change after the student views a demonstration of a laboratory experiment?
3. How are changes in understanding different between these two approaches?
4. How are student opinions of the two approaches different?

Methods

Subjects

Six laboratory sections of students, who were enrolled in a first semester general chemistry lecture course at a large

public southwestern university, were selected to participate. Due to laboratory teaching schedules, three teaching assistants (TA), each teaching two sections, were chosen to participate in the study. Of the two sections for each TA, one was randomly assigned to the control group and the other section assigned to the experimental group in an attempt to yield roughly equal numbers of students in each group. This was also done with the hopes of accounting for differences in TA grading styles. Students in the control group performed the laboratory in the manner customary for this course. Students in the experimental group observed the laboratory performed as a demonstration.

Instruments

In order to assess group equivalency on logical reasoning or formal thought, Test of Logical Thinking (TOLT) (Tobin and Capie 1981) scores were collected for the students. This exam has been used by researchers for this purpose (e.g., Williamson and Rowe 2002) and linked to achievement in chemistry (Lewis and Lewis 2007). Types of logic tested on this instrument are control of variables, proportions, combinations/permutations, correlations, and probability. There are two questions of each type, for a total of 10 questions. The standard scoring system for this instrument was used, producing a score in the range 0–10, inclusive. For each question, students must get both the answer and the reason correct to be awarded the point for the item. The internal reliability is 0.85 for students from grade 6 through college-level.

The "Reactions of Calcium" laboratory from the 2002 edition of "Experiences in Chemistry—I" (Peck and Williamson 2001) was used in this investigation. The standard report form for this laboratory, as graded by the student's TA, was used as a measure of student performance explicitly on the laboratory experiment. This laboratory experiment is performed each semester as a part of the first semester chemistry course at the university. The laboratory experiment was originally designed as a guided inquiry. A guided inquiry enables students to collect qualitative data, which can then be used to make a prediction. The second part of the lab required students to gather quantitative data to support the predictions made from the qualitative data. Thus this experiment places emphasis on both a student's ability to collect data and on a student's ability to analyze this data in order to identify a trend in their data. The multiple page report form includes data recording, analysis questions requiring qualitative and quantitative inferences from the observational data, directions to look for patterns by graphing, and summary questions, which ask for evidence for any conclusions. The laboratory develops the concept that calcium and hydrochloric acid react to produce hydrogen gas, following a balanced equation with a 1:2 molar ratio. The laboratory further investigates the products of the reaction between sodium hydroxide and hydrochloric acid.

A pre- and post-test were given to the students as a measure of increased conceptual understanding. Both the pre- and delayed post-test contained similar questions, which were designed to cover the content learned in the laboratory experiment; however on the post-test, an open-ended question was added to assess student attitudes of the laboratory investigation. The post-test was given approximately 2 weeks after completion of the laboratory investigation. Examples of the pre- and post-test questions can be seen in Table 1.

Data and Analysis

A breakdown of the participants by TA and group is given in Table 2. Since each section had slightly different enrollment, the sample was further limited by random selection of participant counts between experimental and control for each individual TA producing an equalized sample. This ensures that each TA contributes equally to both the control and experimental groups.

Of the 70 total participants in the study 42 (60.00%) were female with the remaining 28 (40.00%) male. Most (85.71%) were in the first year of college with over 90% within the first 2 years in college. There were a wide variety of majors from various colleges within the university represented in the sample.

Table 1 Sample questions

Sample pre-test questions
What reaction occurs when calcium metal is mixed with aqueous HBr?
Given the reaction you wrote in #1, how many mL of 0.105 M HBr is needed to react with 0.2011 g of calcium metal?
What reaction occurs when HBr is reacted with NaOH?
Sample post-test questions
What gas is produced when reacting calcium metal with HCl?
How many g of the gaseous product from #1 can be produced from 10.00 mL of 0.102 M HCl reacted with 0.2036 g calcium metal?
What is the reaction between HCl and NaOH?

Table 2 Sample selection

TA	Initial count		Equalized sample	
	Cont	Exp	Cont	Exp
1	13	21	13	13
2	13	12	12	12
3	10	13	10	10
Total	36	46	35	35

The average scores (standard deviation) are summarized in Table 3 for all assessments given. No differences were found in the assessments by demographics therefore these will not be discussed. All instruments were graded by the TA for the section in question except for the TOLT, which was graded by the investigator. Pre-test and Post-test questions were graded on a correct/incorrect basis based upon a key provided by the investigator. The laboratory report form was the only instrument which was subjectively graded by the TAs. A statistical analysis was performed upon this data to determine if any significant differences exist. Table 3 also shows the p-value from an ANOVA test between control and experimental groups for each instrument without any use of any covariates.

In order to determine if the students knowledge changed between the pre-test and post-test, a paired t-test was conducted on the overall average for all subjects on the pre-test and post-test. A significant difference for all subjects was found, ($p = 0.0056$), indicating a significant increase in student learning from the pre-test to the post-test. Further differences in the pre-test and post-test were evaluated for each treatment group. A significant difference ($p = 0.0022$) was found between the pre- and post-tests of the experimental group (56.6–70.0%), while there was no difference for the control group (66.3–66.7%). The control group post-test average was moderated by TA1. This finding led to an analysis omitting TA1, which gave a significant difference between the pre- and post-test for the control group ($p = 0.028$) and the experimental group ($p = 0.0043$), indicating learning occurred for both groups.

Before looking for differences between groups, the individual TA scores were examined. When looking at the pre-test scores for each TA, combining the control and experimental group for that TA, there is a significant difference between the three TAs ($p = 0.0364$). Since the pre-test was graded objectively, this difference can be attributed solely to differences between student groups, and not to differences among TA grading styles. Due to the existence of this difference, the pre-test will be used as a covariate, unless only the change in score between pre-test and post-test is being analyzed. A significant difference between groups is evident on the TOLT ($p = 0.0492$), so the TOLT score will also be used as a covariate. Table 4 summarizes the findings of the scores from the report, from the post-test and the change in understanding from pre- to post-testing when covariates are used. The covariates used are noted in the table. No significant differences were found between the two groups on the report, the post-test, or the gain in understanding from pre- to post-test.

The student opinion questions were also examined. Of the 70 participants analyzed, 62 answered the opinion question. The control group was asked if they thought they would have benefited more by observing a TA perform the procedures of the lab. The experimental group was asked if they thought they would have benefited more by performing this lab in a hands-on fashion. The majority of these responses, 35 of the 62, seem to indicate that the students believed that they would learn the material better by doing the experiment themselves (hands-on preference), while 22 indicated that they believed that they would learn more with demonstration. The frequency of the most popular responses for each preference is summarized in Table 5. Examples of student responses from the control group are:

> "We just follow the instructions & don't really know why we did what we did"
> "I was very insecure when doing the lab"
> "I learn better if I do it myself"

Table 3 Dataset analyzed (each group n = 35)

TA	n		TOLT (0–10)		Pre-test (0–100%)		Report (0–100%)		Post-test (0–100%)	
	Cont	Exp	Cont	Exp	Cont	Exp	Cont	Exp	Cont	Exp
1	13	13	7.8 (1.8)	7.5 (1.7)	66.7 (30.0)	73.3 (26.7)	57.9 (20.1)	71.0 (9.8)	56.6 (26.7)	80.0 (26.7)
2	12	12	8.3 (2.1)	7.8 (2.2)	60.0 (20.0)	53.3 (30.0)	58.5 (19.7)	66.9 (20.1)	70.0 (26.7)	70.0 (20.0)
3	10	10	8.5 (1.6)	6.3 (2.1)	60.0 (26.7)	33.3 (16.7)	79.3 (7.2)	57.5 (20.0)	73.3 (36.7)	53.3 (23.3)
Total	35	35	8.2 (1.9)	7.2 (2.0)	63.3 (30.0)	56.6 (30.0)	65.2 (20.1)	65.2 (19.8)	66.7 (30.0)	70.0 (26.7)
Overall averages			7.7 (1.9)		60.0 (30.0)		65.2 (20.1)		66.7 (26.7)	
p-value			0.0492		0.1962		0.6179		0.9368	

Table 4 ANCOVA results—with listed covariates

	Report (0–100%)		Post-test (0–100%)		Gain-pre to post (0–100%)	
	Cont	Exp	Cont	Exp	Cont	Exp
Average score	65.2 (20.1)	65.2 (19.8)	66.7 (30.0)	70.0 (26.7)	33.3 (26.7)	16.7 (26.7)
p-value	0.9412		0.4784		0.0510	
Covariate	TOLT & Pre-test		TOLT & Pre-test		TOLT	

Table 5 Frequency of most popular answers for each group

Preference	Answer	Frequency	Percentage
Hands-on	I learn more from hands-on activities	25	71.43
	Pay more attention when I am doing it	7	20.00
Demo	Less mistakes would be made in demo	12	54.55
	The procedure is new, difficult, or unclear	9	40.91
	I could concentrate on the demo because I do not have to concentrate on procedure	4	18.18
	The events are explained better	4	18.18
	I am a visual learner	2	9.09

"I don't think I would understand the concepts associated with the lab as well"

"I learn more by actually doing the lab myself"

Examples of student responses from the experimental group are:

"It took less time and was easier to understand"

"I always learn more when I do them myself"

"No mistakes were made, so the experiment worked out nicely"

"I can learn from my mistakes therefore enabling me to be able to conduct....future experiments"

"I remember things that I do better than what others do for me"

Conclusions and Implications

The results seem to indicate that if students have achieved a formal level of reasoning, significant gains in conceptual understanding will be seen whether a hands-on inquiry experiment or an inquiry demonstration is performed. Both the hands-on and demonstration laboratories studied here provide the students with the same things to observe. In the case of the demonstration, the instructor can insure that the experiment is carried out properly and that salient events can be emphasized. The cognitive processes required to analyze the observational data obtained were the same for either group. Both groups looked for patterns from which they could make generalizations from the observational data. It may be that the power of the inquiry style laboratory is in the logic required to analyze the data. There were no significant differences found between the groups on any measure used in this study. It seems that it is possible to substitute demonstrations for hands-on experimentation without decreasing student learning, if the demonstrations are carried out in an inquiry fashion. However, with the demonstration, students do not have the chance to learn the laboratory techniques, which they would learn in the normal inquiry experiment. Inquiry demonstrations might be most beneficial in courses, which are pressed for the time and funds, required by laboratory experiments.

However, it is important to keep in mind the limitations of this study. The demonstration was limited to a single experiment, which was performed using a guided inquiry format. It is not clear if these results can be generalized to other inquiry laboratory experiments covering different content. No effort was made to determine if the observed effects are applicable to traditional or other styles of laboratories or if the same effects would be found using show-and-tell demonstrations in the place of inquiry demonstrations. Furthermore, whether this style of instruction is equally beneficial to various reasoning ability levels was not measured. The groups used here had fairly high TOLT scores. Also, only one open-ended opinion question was asked on the post-test to gage the effect this style of instruction had on students' attitudes. A relatively small number of pre- and post-test questions were used to determine changes in student learning. Finally, no attempt was made to decompose gains in student learning into that,

which was engendered by the laboratory and that which arose from the lecture portion of the course. All these factors need further study in order to be fully addressed. This study does show that inquiry demonstration is a viable option with the population, content, and circumstances described; however, before the use of inquiry demonstrations can be used routinely as an alternative means of instruction to hands-on, inquiry-based laboratories with the general population, more research must be done.

References

Abraham MR et al (1997) The nature and state of general chemistry laboratory courses offered by colleges and universities in the united states. J Chem Educ 74:591

Abraham MR, Renner JR (1986) The sequence of learning cycle activities in high school chemistry. J Res Sci Teach 23:121

Anibel FG (1926) Comparative effectiveness of the lecture-demonstration and individual laboratory method. J Educ Res 15:355

Bowen CW, Phelps AJ (1997) Demonstration-based cooperative testing in general chemistry: a broader assessment-of-learning technique. J Chem Educ 74:715

Carptenter WW (1936) A study of the comparison of different methods of laboratory practice on the basis of results obtained on the basis of results obtained on tests of certain classes in high-school chemistry. J Chem Educ 3:798

Cooke RL (1938) Demonstration versus laboratory once again. J Chem Educ 15:592

Deese WC, Ramsey LL, Walczyk J, Eddy D (2000) Using demonstration assessments to improve learning. J Chem Educ 77:1511

Domin DS (1999a) A content analysis for general chemistry laboratory manuals for evidence of higher-order cognitive tasks. J Chem Educ 76:109

Domin DS (1999b) A review of laboratory instruction styles. J Chem Educ 76:543

Eniaiyeju PA (1983) The comparative effects of teacher-demonstrations and self-paced instruction on concept acquisition and problem-solving skills of college level chemistry students. J Res Sci Teach 20:795

Harty H, Al-Faled N (1983) Saudi Arabian students' chemistry achievement and science attitudes stemming from lecture demonstration and small group teaching methods. J Res Sci Teach 20:861

Hilosky A, Sutman F, Schmukler J (1998) Is laboratory-based instruction in beginning college-level chemistry worth the effort and expense. J Chem Educ 75:100

Knox WW (1936) The demonstration method of teaching chemistry. J Chem Educ 13:166

Lawon AE (1988) A better way to teach biology. Am Biol Teach 50:266

Lewis SE, Lewis JE (2007) Predicting at-risk students in general chemistry: comparing formal thought to a general achievement measure. Chem Educ Res Pract 8(1):32–51

Pavelich MJ, Abraham MR (1979). An inquiry format laboratory program for general chemistry. J Chem Educ 56:100

Payne VF (1932) The lecture demonstration and individual laboratory methods compared. I. The literature. J Chem Educ 9:932

Peck ML, Williamson VM (2001) Experiences in chemistry—I. Hayden McNeil Publishing, Plymouth, MI, p 49

Renner JW, Marek EA (1990) An educational theory base for science teaching. J Res Sci Teach 27:241

Shiland TW (1999) Constructivism: the implications for laboratory work. J Chem Educ 76:107

Staver JR, Small L (1990) Toward a clearer representation of the crisis in science education. J Res Sci Teach 27:79

Tobin KG, Capie W (1981) The development and validation of a group test of logical thinking. Educ Psychol Meas 41:413

Williamson VM, Rowe MW (2002) Group problem solving versus lecture in college-level quantitative analysis: the good, the bad, and the ugly. J Chem Educ 79(9):1131–1134